ALTERNATIVE CLEAN FUELS FOR TRANSPORTATION IN APEC ECONOMIES[1]

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ABSTRACT

A study has been undertaken for APEC to compile and analyze data from APEC economies on transportation fuels and emissions, and to identify potential future petroleum and alternative fuels and vehicles that could reduce emissions and associated air quality impacts from the transportation sector. Results of the survey of APEC transportation energy demand, fuel quality parameters and vehicle fleet data are summarized. Based on these results, clean fuel and vehicle options and their potential to reduce emissions are identified and discussed.

1 INTRODUCTION

This paper utilizes information developed from a survey of APEC economies conducted to determine present and forecast data in the following areas: transportation energy demand; vehicle fuel economy and vehicle fleet profile statistics; fuel specifications; current and potential energy resources for transportation fuels; and national emissions of common and greenhouse gas emissions. The data acquired from this survey was supplemented using information from published reports and papers and from internet web sites to try filling data gaps.

A review of transportation fuel energy source options and technologies, as well as fuel specifications as they relate to emissions from motor vehicles was conducted for the APEC economies drawing on the survey data to characterize the existing fuels. The focus of the fuel energy source technologies and fuel specifications was focused on identifying future petroleum and alternative fuel options for the on-road transportation sector.

The study reported in this paper was done with guidance and support from the APEC Expert's Group on Clean Fossil Energy.

2 APEC TRANSPORTATION ENERGY AND ON-ROAD VEHICLE DATA

Results were provided by nine APEC economies on the on-road transportation energy demand. This segment of the transportation sector consumes 80-89% of the total transportation energy demand, which also includes aviation, rail, and marine transportation. The second largest segment of the transportation sector is aviation, consuming 7-18% of the reported total energy used for transportation.

Gasoline is the dominant transportation fuel in most APEC economies, followed next by diesel fuel. The relative demand for these fuels varies significantly in the APEC region, depending on the vehicle fleet profile. This is significant when assessing the options and ramifications of future clean fuel options. Table 1 shows gasoline comprises as high as 57-62% of the total fuel energy demand in the USA, Mexico, Chinese Taipei and Malaysia, and levels in the range of 45-53% in other developed economies. The lowest share of gasoline demand and, correspondingly, the highest share of diesel fuel demand were reported for Thailand and Peru.

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Table 1 Reported Percent and Total Transportation Fuel Demand in APEC Economies

Economy	Total Transportation Energy Demand (PJ)	Year	Percent of Current Total Transportation Energy Demand		
			Gasoline	Diesel Fuel	Other Fuels
Australia	1,408	1998/99	45.4	40.1	14.5
Canada	2,397	1997	53.0	34.8	12.2
Chinese Taipei	544	1998	57.3	26.0	16.7
Japan	4,038	1997	48.0	41.7	10.3
Malaysia	427	1998	59.7	23.6	16.7
Mexico	1,719	1999	58.8	33.2	8.0
New Zealand	185	1999	50.7	30.4	18.9
Peru	145	1998	33.7	55.3	11.0
Thailand	837	1998	31.7	54.0	14.3
United States	26,091	1998	62.2	20.0	17.8

The survey results are consistent with data reported for 1997 by the US Energy Information Administration (US EIA, 2000).

Table 2 summarizes the reported distribution of motor vehicles by class of vehicle and shows the significant differences that exist in the vehicles of choice in the APEC region. Gasoline passenger cars are a high percentage of the fleet in developed APEC economies, and low in developing economies. Although the number of passenger car numbers is lower in developing economies, this is accompanied by large numbers of motorcycles. Light duty trucks, vans and sport utility vehicles comprise 29-33% of the vehicle fleet in North America, while it is lower in other economies, with the lowest level reported for Chinese Taipei at 6.2%. Diesel passenger cars are a minor part of the fleet in all economies, ranging from less than 1% in North America to a high of 5.8% in Japan. Total vehicle numbers per 1000 people are 564-735 for developed economies, compared to under a 100 for the two reporting developing

Table 2 Vehicle Fleet Profiles by Vehicle Type for APEC Economies

	Canada	United States	Australia	Japan	New Zealand	Chinese Taipei	Malaysia	Philippines	Singapore	Thailand*
Passenger Cars (%)										
Gasoline	61.7	60.8	75.7	54.1	74.9	45.6	36.9	21.9	59.3	32.6
Diesel fuel	0.6	0.6	1.8	5.8	0.5	0.9	0.2	0.9	0.0	8.0
Other	0.5	0.2	1.5	0.3	0.9	0.1	0.0	0.0	0.0	0.0
Subtotal	62.9	61.6	79.0	60.2	76.4	46.5	37.2	22.8	59.3	40.5
Motorcycles (%)	1.9	1.9	2.7	17.2	3.4	45.4	57.2	31.4	20.6	41.3
Light Duty Trucks (%) Gasoline	28.4	32.0	10.8	14.9	9.1	4.3	1.1	16.0	7.5	0.0
Diesel fuel	0.2	1.1	3.5	6.7	5.8	1.9	2.4	21.8	7.2	14.9
Other	0.7	0.2	0.6	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Subtotal	29.3	33.3	14.8	21.7	15.5	6.2	3.5	37.8	14.7	14.9
Heavy Duty Trucks (%)										
Gasoline	2.1	1.2	0.7	0.0	0.5	0.0	0.0	0.2	0.0	0.0
Diesel fuel	3.9	1.9	2.8	0.9	4.2	1.9	2.1	7.8	5.4	3.2
Subtotal	6.0	3.1	3.5	0.9	4.7	1.9	2.2	8.0	5.4	3.2
Total Vehicles (1000)	17,083	198,346	12,067	82,958	2,343	9,870	8,842	3,289	646	3,986
Vehicles/1000 people	564	735	642	656	633	453	398	45	202	65

* Vehicle data for Bangkok only.

economies, eluding to the potential impact on transportation-related emissions if vehicle mobility levels in the developing economies rise to the present level in developed economies.

Eight APEC economies provided data on the fuel economy of the on-road vehicle fleet and these are shown in Figure 1. Most fuel economy values for on-road passenger cars are 8-10 km/L. The higher vales reported by New Zealand and Malaysia are unusually high and, for this reason, suspected to apply to test values for new vehicles, which would be higher than the fleet average fuel economy reported by other economies. The fuel economies of light duty trucks are 6-8 km/L, while the fuel economies for heavy-duty diesel vehicles are mostly in the range of 2.2-3.2 km/L.

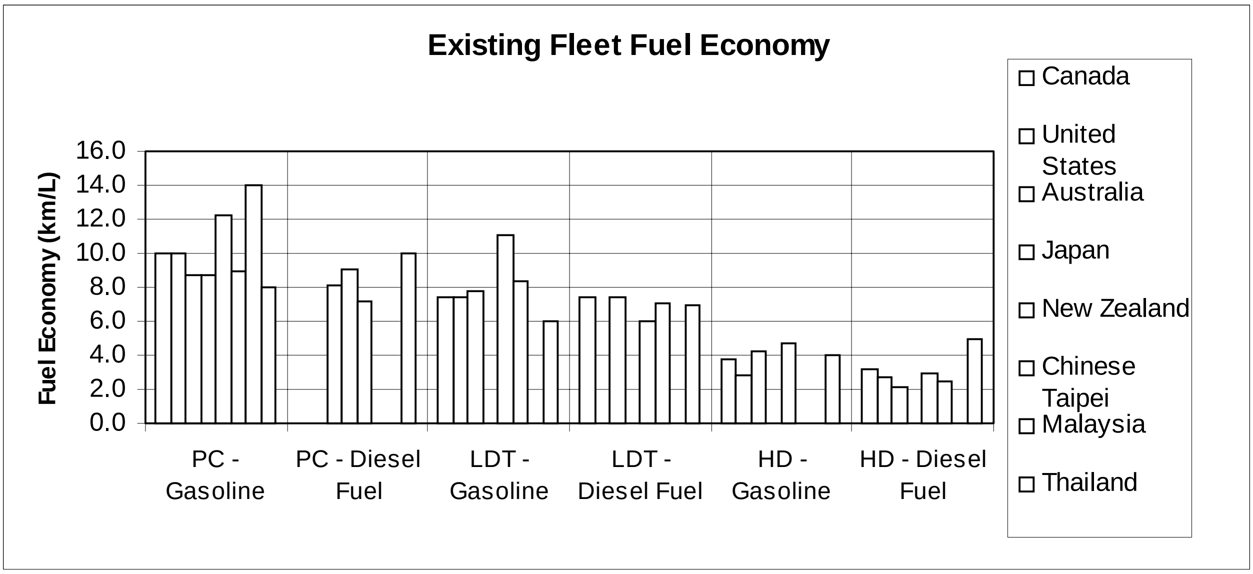


Figure 1

Fleet fuel economy and emissions are strongly affected by the age distribution of the on-road fleet, which is dependent on new vehicle characteristics and the rate of fleet turnover. The highest proportion of 0-5 year old passenger cars in the vehicle fleet was reported for Japan at 50%. New Zealand reported a relatively low proportion of 0-5 year old vehicles and higher proportions of older vehicles.

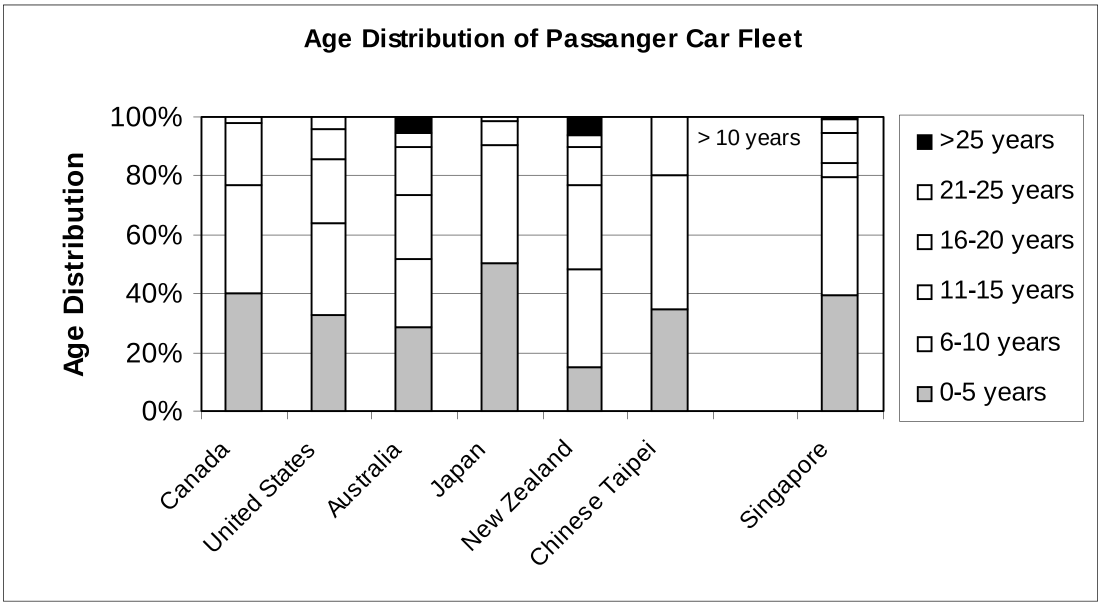


Figure 2

Information was requested from the APEC economies on key parameters that influence emissions and fuel performance, and the results received are shown in Table 3. Recent initiatives in some APEC economies will reduce the future maximum gasoline sulphur content to 0.003 % to enable the latest vehicle emission control equipment to function effectively. The average gasoline sulphur content is well above this level in all reporting economies, which adversely affects the performance of catalytic emission control systems. Many of the APEC economies have reduced the maximum allowable sulphur content of motor diesel fuel to 0.05%, which can help lower SO_2 and particulate emissions from the vehicle fleet. Minimum required cetane levels were found to be lowest in Canada, the US and Chinese Taipei. Some APEC economies have reduced aromatics and benzene contents of gasoline, with the lowest regulated level being 1 vol %. This trend reduces emissions of benzene and other potential air toxics.

Table 3 Reported Fuel Characteristics for APEC Economies

	Canada	Mexico	United States	Australia	Japan	New Zealand	Chinese Taipei	Hong Kong	Malaysia	Philippines	Singapore	Thailand	Peru
Gasoline													
RVP - Summer, low, kPa	55	45	60	73.6	44	77.5	61.3	-	62	80	45	62	82.7
RVP - Summer, high, kPa	107	59	60	73.6	78	115	61.3	-	62	80	62	62	82.7
RVP - Winter, low, kPa	107	45	79.6	83.4	44	77.5	61.3	-	-	-	45	-	82.7
RVP - Winter -high, kPa	107	66	79.6	83.4	93	115	61.3	-	-	-	62	-	82.7
Gasoline avg wt % S	0.035	-	0.034	0.015	-	-	-	-	-	-	0.013	-	0.02
Gasoline max wt % S	0.1	0.05	0.12	0.2	0.01	0.05	0.0275	0.05	0.15	0.1	-	0.1	0.15
Olefins (vol %)	10.6	15	10.8	17.1	-	-	-	-	-	-	-	-	-
Aromatics (vol %)	26.2	30	28.6	45	-	48	-	-	-	45	-	50	-
Benzene (vol %)	1	2	1.6	5	5	5	1	5	-	4	5	3.5	-
Diesel Fuel													
Cetane Number (min)	40	48	40	45	45	45	40	50	58.5	45	-	46	45
Diesel Fuel avg wt % S	0.05	-	-	0.13	-	-	-	-	0.08	-	0.50	-	0.2
Diesel Fuel max wt % S	0.05	0.05	0.05	0.5	0.05	0.3	1	0.05	0.1	0.5	1	0.05	0.7

Emission data can be used to guide air quality and emission control planning activities, nationally or regionally. Emission inventory data was obtained for APEC economies to determine the contribution to total emissions made by transportation sources. Emission data was found to be difficult to obtain and was only available from eight of the APEC economies. As illustrated in Figure 3, total transportation sources are a major contributor to NO_x, a precursor to ground-level ozone and fine particulate. The transportation sector is also a major contributor (40-90%) to total reported CO emissions. APEC economies reported 10-90% of total non-methane hydrocarbon emissions were from the transportation sector. The wide variability in the reported results for non-methane hydrocarbon emissions may be partly due to differences in methodology and the completeness of the emission inventories.

Total transportation sources comprise 20-40% of the total national inventories of carbon dioxide emissions, as reported by Canada, the US, Australia, Japan, Hong Kong and Thailand.

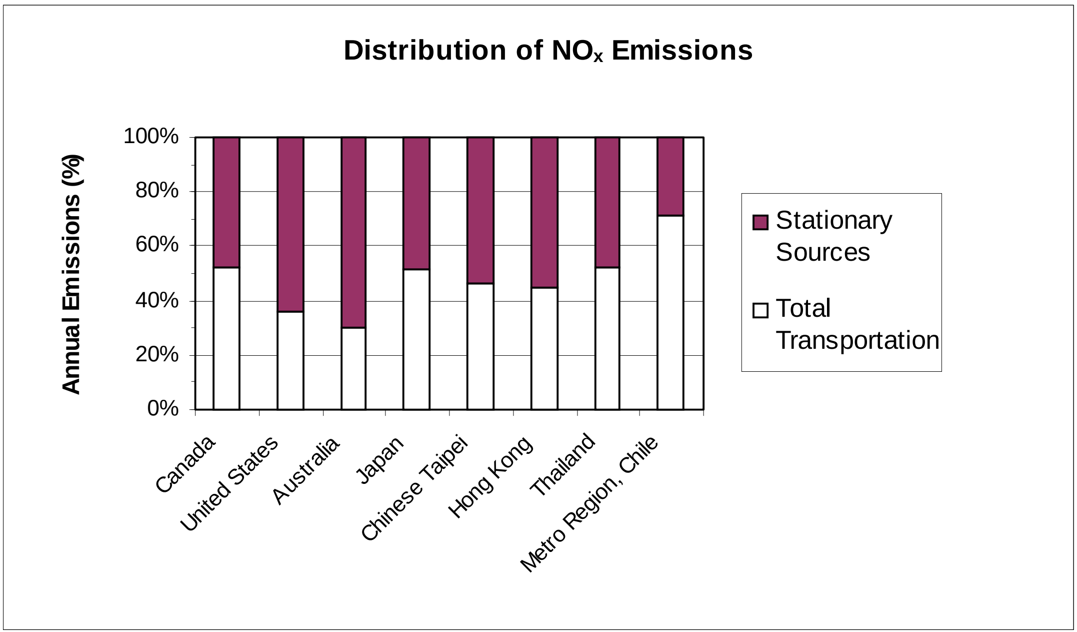
3 FUTURE PETROLEUM AND ALTERNATIVE FUEL OPTIONS

Most of the APEC economies have petroleum refineries to supply fuels for their transportation sector and other applications. All economies are involved in the import and export of refined petroleum products.

Petroleum Fuels

Extensive research has been conducted in the past decade to better understand the influence of gasoline and diesel fuel quality and composition parameters on vehicle emissions, much of it focused on gasoline. Because of heightened concern about the health impacts of diesel particulate matter and EPA's proposed standards for diesel engines, extensive research is being done on the effects of diesel fuel and diesel engine design on emissions. Dramatic advances are also being made in vehicle technologies to reduce tailpipe emissions and increase fuel economy, while providing good drivability and performance. Improvements to motor vehicles in these areas are creating requirements to improve the quality of petroleum fuels and utilize more effective additives, as well as stimulating interest in alternative fuels and energy sources suited to future advanced vehicle designs.

Figure 3



A recent presentation from the California Air Resources Board (1999) summarized the emissions response to gasoline parameters as shown in Table 4.

Table 4 Summary of Emission Response to Gasoline Parameter Changes

Decreasing Fuel Parameter	Leads to
Fuel vapor pressure (RVP)	Reduced evaporative VOC's
Sulphur	Reduced VOC's, NO_x, Toxics, SO_x
Benzene	Reduced Toxics
Aromatics	Reduced VOC's, NO_x, Toxics
Olefins	Reduced NO_x, Toxics, Increased VOC's
T50 and T90 distillation point temperatures	Reduced VOC's, Toxics, Increased NO_x
Oxygen	Increased VOC's, Toxics, CO, Reduced NO_x

Gasoline is formulated to meet many quality parameters including octane, volatility, drivability, and energy content. In addition a refiner must simultaneously meet the quality specifications of the other products being produced. The result is that it is extremely difficult to change only one parameter at a time. For example aromatics are a good source of octane, so lowering aromatics to reduce VOC's, NO_x and toxics must be offset by increasing another component that will restore octane.

Adding an oxygenate to gasoline such as ethanol or MTBE, not only reduces VOC's, CO, and Toxics and increases NO_x it also adds octane so the aromatics can be reduced. A refiner that takes full advantage of the properties of the oxygenate can therefore reduce VOC's and toxics further and offset at least some of the NO_x increase usually associated with oxygenates. The oxygenate will also dilute some of the other gasoline parameters such as benzene and sulphur leading to further small improvements in air quality.

Automobile manufacturers around the world in recent years (Alliance of Automobile Manufacturers, 2000) have published their recommendations for gasoline and diesel fuel quality. These recommendations have been issued in part in response to emerging needs and in some cases regulations for more stringent vehicle emission control and reduced fuel consumption. Fuel specifications can impact directly on emissions and fuel economy as shown above and they can also act as technology enablers for new advanced emission control strategies. The Alliance of Automobile Manufactures in conjunction with the European Automobile Manufacturers Association, the Engine

Manufacturers Association and the Japan Automobile Manufacturers Association issued a revised World-Wide Fuel Charter in April, 2000 to address the need to more stringent standards on fuel sulphur that will be necessary to enable future vehicle technology to meet emerging requirements for vehicle fuel economy and vehicle emissions. This new proposal is summarized in Table 5.

Table 5 Summary of Worldwide Fuel Charter for Gasoline.

Property	Units	Category 1	Category 2	Category 3	Category 4
Octane[2]	MON	82.0	82.5	82.5	82.5
	RON	91.0	91.0	91.0	91.0
	R+M/2	86.5	86.75	86.75	86.75
Sulphur	ppm	1000	200	30	Sulphur-free[3]
Lead	g/L	0.4[4]	Non-detectable (n.d.)	n.d.	n.d.
Phosphorus	g/L	No spec	n.d.	n.d.	n.d.
Manganese	g/L	Not added[5]	n.d.	n.d.	n.d.
Silicon	g/L	No spec	n.d.	n.d.	n.d.
Oxygen	% wt	2.7[6]	2.7[5]	2.7[5]	2.7[5]
Olefins	% v/v	No spec	20.0	10.0	10.0
Aromatics	% v/v	50.0	40.0	35.0	35.0
Benzene	% v/v	5.0	2.5	1.0	1.0
Volatility End Point	C	215	195	195	195
Density	Kg/m^3	715-780	715-770	715-770	715-770
Inlet Valve Cleanliness	mg/valve	Requires additive	50	30	30
Combusti on Chamber Deposits	mg/engine	No spec	3500	2500	2500

Gasoline specifications for any economy rarely follow exactly all the requirements for a category. Many of the industrialized economies are in the process of moving their specifications toward Category 3. The World-wide Fuel Charter provides a good basis for identifying changes being encouraged by the vehicle manufacturer to reduce emissions and improve vehicle efficiency and is a useful reference when evaluating the merits of alternative and future fuel strategies.

Some highlights of the effects on vehicle emissions of the changes in gasoline parameters suggested in the World-Wide Fuel Charter are:

- Octane - most economies meet the advanced requirements;
- Sulphur content - reducing sulphur content will improve the performance of catalytic control systems on vehicles and, hence, achieve or enable lower tailpipe emission levels. For example, reducing gasoline sulphur content from 330 to 30 ppm will reduce HC 13.6%, CO 16.6% and NO_x 7.1% for pre-1994 US vehicles and HC 33.2%, CO 43% and NO_x 57.2% for advanced LEV vehicles.
- Lead - not all economies have phased out lead from motor fuels, but lead-free gasoline will be needed in all areas for advanced emission controls and to reduce lead exposure.
- Oxygenates - use of MTBE as an oxygenate is under attack in the United States for environmental reasons because of concern about impacts to groundwater quality. The fuel charter accepts the use of ethanol as an oxygenate. Oxygenates reduce exhaust emissions and, when ethanol from biomass feedstocks is used, reduce full cycle greenhouse gas emissions.
- Aromatics and benzene - reduced aromatics reduce hydrocarbons, NO_x and toxics. Reduction of benzene is a priority compound because it is a known carcinogen.
- Volatility - lower vapor pressure reduces evaporative emissions and lower T10 and T90 reduce hydrocarbon emissions and air toxics at the expense of NO_x.

The worldwide fuel charter has also developed guidelines for motor diesel fuel. A minimum Cetane number for diesel fuel of 48 to, preferably, 55 are recommended. The Cetane quality is lowest

[2] Lowest grade shown here.
[3] 5-10 ppm based on available data. To be more specific when more data is available.
[4] Where legally permitted. Otherwise 0.013 g/L.
[5] Not intentionally added.
[6] Ethers preferred, but up to 10% ethanol where permitted. No methanol.

in North America and excellent in many of the APEC economies. The Fuel Charter suggests the maximum sulphur content of diesel fuel decrease from 0.03% in Category 2 to 0.003% in Category 3 and be sulphur-free in Category 4. Reductions of diesel sulphur to very low or negligible levels will be needed to enable the use of catalytic after-treatment systems to reduce NO_x emissions. Lower diesel fuel sulphur content will also reduce particulate matter and sulphur dioxide emissions.

Natural Gas

Natural gas is a clean burning fuel for motor vehicles and an attractive option where there is an abundant supply and distribution network, a need to address deteriorating air quality and favorable regulatory and economic environment for alternative motor fuels. Natural gas can be compressed and stored on the vehicle as compressed natural gas (CNG) at a pressure of 3,000 to 5000 psi, or as liquefied natural gas (LNG) at a temperature of -159 C.

Natural gas has been used as a motor vehicle fuels for many years and there are approximately 1.2 million vehicles operating on natural gas worldwide. This is about 0.18% of the vehicle fleet. From a performance and emissions viewpoint, natural gas has the following attributes:

- exhaust emissions from after-market converted gasoline vehicles can be lower or higher than that for the original vehicle. Factory conversions have lower emissions than an equivalent gasoline vehicle.
- Natural gas has an octane rating of 130, making it suitable for high compression, efficient engines, though few manufacturers take advantage of this potential.
- A diesel pilot fuel is needed in converted diesel engines to provide an ignition source and these engines are less efficient that the original equipment. A new technology is being developed by Westport Innovations of Vancouver, Canada, which retains the high efficiency of a compression ignition engines while operating on natural gas opening up market potential for greater application of natural gas in motor vehicles and stationary engines.
- Dedicated factory built natural gas vehicles have been certified to low California Ultra Low Emission Vehicle standards. Compared to the same vehicle burning US average gasoline, emission reductions of 96-97% for no methane hydrocarbons, 90-63% for CO, 69-81% for NO_x and 26-17% for CO_2 were measured for natural gas fuelled Honda Civic and Ford F250 truck, respectively.
- CNG buses emit 70% less NO_x, 90 % less CO and 90% less particulate matter than diesel buses (Onursal and Gautam, 1997), but the buses and the refueling station are significantly more expensive.
- Natural gas offers a potential reduction in full cycle greenhouse gas emissions of 20-25% in Canada.
- Barriers to greater use of natural gas in motor vehicles are limited fuel distribution network, vehicle range, loss of storage space and higher weight, and higher vehicle price.

Programs are active in many APEC economies to promote the use of natural gas fuelled vehicles, including Indonesia, Australia, Canada, US, Japan, Malaysia, Russia, Thailand, China and Korea.

Liquid Petroleum Gases

Liquid petroleum gases (LPG) are primarily composed of propane and butane, with smaller amounts of ethane and other hydrocarbons. LPG is available in areas having a natural gas processing industry or from oil refineries where butane and propane are by-products of oil refining.

Use of LPG in motor vehicles is well-established technology, both with after-market conversions and more efficient factory built vehicles. About 4 million LPG fuelled vehicles are in-use worldwide. LPG vehicles are very popular in Japan, Thailand and Korea, and are in use in many other APEC economies. LPG is used extensively in Latin America and the Caribbean, including Mexico, Peru and several other economies in this region. Nissan and Toyota in Japan, Hyundai in Korea and Ford in the United States manufacture medium duty and some models of light duty trucks for LPG. Most current LPG vehicles in use are conversions from gasoline-fueled vehicles.

LPG has an octane rating of about 104, making it well suited to spark ignition engines, but not suited to compression ignition engines. Many LPG vehicles are dual fuel designs, allowing the user to switch to gasoline. These vehicles are not optimized to take advantage of the higher LPG octane rating.

Although one of the main benefits of LPG is lower cost of fuel compared to gasoline, LPG offers some potential emission benefits. Ford LPG/gasoline dual fuelled F-250 light duty trucks meets Ultra Low Emission Vehicle standards, though CO and NO_x were higher than with gasoline, while nonmethane hydrocarbons were lower. Other literature (Onursal and Gautam, 1997) has reported conventional LPG fueled vehicles have 25-80% lower CO, similar NO_x (when equipped with catalytic converters) and lower particulate matter. The full cycle reduction in greenhouse gas emissions achievable with LPG compared to gasoline is in the order of 20 % for Canada.

Alcohols

Methanol and ethanol are the two alcohol fuels that have been used for transportation fuels. Both have been used as low-level and high-level blends in gasoline.

Methanol has been used as motor fuel in gasoline blends at concentrations of 5% (as a cosolvent), 15 % (M15) and 85% (M85). Low-level methanol blends (5%) are not accepted under the worldwide fuel charter. Interest and use of M15 and M85 has stagnated or is declining in North America as a result of the advances made with reformulated petroleum fuels and advanced engines, preference for other alternative fuels and greater appreciation of the difficulty of marketing the fuel and vehicles. M85 offers excellent vehicle performance and lower exhaust emissions compared to gasoline. Methanol fuelled vehicles emit a higher level of formaldehyde than gasoline vehicles.

There is heightened interest in methanol as a motor fuel with the development of fuel cell vehicles since methanol is the easiest fuel to reform to hydrogen used in current hydrogen fuel cell vehicles. Some companies are working on direct methanol fuel cells, which would eliminate on-board conversion of methanol to hydrogen presently required, thereby simplifying the onboard fuel system. Testing of methanol fuel cell vehicles is planned in California beginning in about 2002. Methanol fuel cells offer the potential for very low vehicle emissions and a 40% reduction in full cycle greenhouse as emissions if the methanol is made from natural gas and perhaps 15% if the methanol is made from coal, when compared to gasoline fuelled vehicles.

Ethanol

Ethanol is made commercially by catalytic hydrogenation of ethylene, or by fermentation of sugars from sugar crops or made by hydrolysis of starch feedstocks. Extensive research and development has been conducted to commercialize ethanol-manufacturing technologies for lignocellulosic feedstocks such as straw, grasses and wood, and some demonstration scale plants have been constructed.

Ethanol has a high octane rating 100-115, which makes it attractive for blending with gasoline to offset the loss of octane that results with fuel reformulation. Ethanol has a high blending vapor pressure and oxygen content. At a 10% concentration in gasoline ethanol adds up to 3 octane numbers and increase vapor pressure by 1 psi.

Large volumes of ethanol/gasoline blends are used as motor fuels worldwide. In 1995, about 11.5 million vehicles in Brazil used ethanol or ethanol blended gasoline. In Paraguay, about 10% of the vehicles use ethanol. About 4.8 billion litres of ethanol were used in the United States in 1998 as motor vehicle fuels, primarily as a 10% ethanol blend.

Ethanol can be used as a 10% blend in gasoline without modification to the engine or vehicle and as an 85 % blend in modified vehicles. The Worldwide fuel charter accepts blends containing up to 7.3% ethanol unless local regulations permit higher concentrations, such as North America. E85 dual-fuel vehicles are manufactured in North America and are offered at the same or higher price as gasoline fuelled vehicles by Ford and Daimler-Chrysler. Unfortunately, many of these vehicles are often being operated on gasoline because of the limited E85 refueling infrastructure.

Extensive testing of ethanol/gasoline blends in current and older vehicles have provided a large database of information on the effects of ethanol on engine emissions. A recent review of this data (S&T Squared, 1999) has concluded that E10. reduces CO emissions 11-33%, reduces hydrocarbons

10-22%, increases NO_x, reduces particulate 25-30% and reduces benzene and 1,3 butadiene emissions. E85 blends have been tested in a Ford Taurus and found to increase CO 31%, increase NO_x 33% and have no change on nonmethane hydrocarbons.

Because CO_2 is absorbed from the air during the growth of biomass feedstocks, their use for ethanol production is a potentially attractive route to reduce greenhouse gas emissions and gasoline consumption. Modeling of full cycle greenhouse gas emissions in Canada (Levelton et al, 1999) determined that, compared to gasoline, E10 offers the potential to reduce greenhouse gas emissions by 4% for corn, 6.7 % for switch grass and 6.4% for hay feedstocks. The full cycle greenhouse gas emission reduction for E85 ranges for a low of 38% with corn to a high of 71% with switch grass.

Biodiesel

Biodiesel is a methyl or ethyl ester of vegetable oil or animal fats and can be used in pure form or as a blend in diesel fuel, with a 20% blend being most common. It can be made from a wide range of feedstocks and using either methanol or ethanol as a reactant. The majority of biodiesel is made today using methanol as the reactant because of high yield, a simpler and low-pressure process and low methanol cost. About one kilogram of oil produces approximately 1.13 litres of biodiesel.

Biodiesel is used commercially in Europe and has some limited markets in the United States. It has been widely tested and its effects on diesel engine power, emissions and engine wear are well known. The positive attributes of biodiesel are: high cetane (60); higher oxygen (9-11% m/m); higher viscosity (4-5 centistokes @ 40C); and negligible sulphur content compared to diesel fuel. It has a 10% lower heating value compared to diesel fuel that has a minor adverse impact on range and refueling frequency. Biodiesel performs well in the engine compared to diesel fuel, with 20% biodiesel blends resulting in a 0-2% power loss and 100% biodiesel resulting in a 0-5% power loss.

Biodiesel at a 20% blend in diesel fuel yields a 5-15% decrease in particulate emissions, 15-20% decrease in hydrocarbon emissions, 1-5% increase in NO_x emissions, 2-16% decrease in CO emissions and a 20% decrease in sulphur oxide emissions. Higher emission reductions are achieved with 100% biodiesel. Levelton et al (1999) estimated that 100 % biodiesel would reduce full cycle greenhouse gas emissions from a vehicle in Canada by 44% compared to the same vehicle using diesel fuel. A similar study for the US estimated a reduction of 41% (Delucchi, 1998).

Synthesized Liquid Fuels

Liquid motor fuels can be synthesized from coal and biomass and from natural gas. This is a potentially attractive source of future transportation fuels for some APEC economies, depending on the available resources and the need for alternatives to petroleum fuels.

Production of liquid fuels from coal and biomass first involves gasification of the feedstock to produce hydrogen and carbon monoxide (syngas). This gas can then be upgraded and converted to liquid hydrocarbons via catalytic Fischer Tropsch synthesis. Products from the F-T synthesis process can be refined to transportation fuels and other synthetic petroleum products using conventional technologies.

Fischer Tropsch synthesis was applied in Germany in the 1930’s and 1940’s and applied in the 1950’s in South Africa. The commercial potential of Fischer Tropsch synthesis has been revitalized by improvements in reactor technology and catalyst capabilities (Cimino, et al, 1998). There are numerous suppliers and developers of gasification technologies for solid feedstocks and development work continues to improve the economics and performance of these technologies.

Fischer-Tropsch synthesis can also be used to transform natural gas feedstock into liquid hydrocarbons. A plant of this type was installed by Shell in Malaysia in 1993 and is still in operation. Alternatively, a methanol synthesis process can be used to produce methanol from natural gas feedstock. This is commercial technology and available as a proprietary process. Methanol can be further processed to produce olefins and gasoline/distillate products. A study by Cimino et al (1998) of the comparative economics of F-T synthesis, methanol synthesis and subsequent processing to make transportation fuels found advanced Fischer Tropsch technology to yield the lowest production costs for gas derived liquid products.

The fuel quality requirements and impacts for liquid fuels synthesized from gas or solid feedstocks can be estimated from the previous discussion of current petroleum and commercial alternative fuels. Issues unique to these synthesized fuels are:

- Gas to liquid technologies are of considerable interest for stranded gas reserves or capture and utilization of flared solution gas, as well as for conversion of syngas to liquid hydrocarbons;
- F-T synthesis is energy intensive and was found to increase full cycle greenhouse gas emissions by 95% in a Canadian context (Levelton et al, 1999) compared to conventional diesel fuel production;
- Syngas production from coal would open up a large potential resource to production of liquid transportation fuels and other synthetic petroleum products. The greenhouse gas emissions of this production route would be higher than liquid fuel synthesized from natural gas and emissions of common contaminants would result from the gasification and synthesis processes.
- Attractive features of F-T diesel fuel from natural gas are its very high cetane number (70) and zero sulphur content;

CONCLUSIONS

1. On-road vehicles are the dominant energy demand within the transportation sector.
2. Gasoline comprises 32-62% of the total transportation energy demand in the APEC economies that provided data for the study, with developed economies tending to be in the high end of this range.
3. Passenger car fuel economy statistics indicate there are opportunities to increase the fleet fuel economy in APEC economies using available vehicle technologies, which would reduce gasoline consumption with fleet turnover.
4. Data for the composition and quality of gasoline and diesel fuel indicates that there are opportunities to reformulate these fuels in the direction suggested by the World-Wide Fuel Charter. Such changes could reduce emissions from the current vehicle fleet and will enable greater reductions to be achieved with the introduction of new vehicles that use modern emission control technologies. A range of gasoline reformulation changes are available to achieve reduced tailpipe emissions from gasoline fuelled vehicles and the optimum strategy depends on the emission control technology used in the vehicle fleet and the options available to the refiners. Reduction of vapor pressure, sulphur content, benzene and aromatics content, use of oxygenates, as well as elimination of lead in gasoline is preferable strategies, and actively being pursued in some APEC economies.
5. Emission reductions could also be achieved by the continued, or greater use of alternative fuels such as natural gas, LPG and alcohol fuels in light duty and medium duty vehicles.
6. Biodiesel as a 20% blend with diesel fuel, or as neat fuel, may be an attractive option in some APEC economies that have supplies of vegetable oils or animal fats and a significant demand for diesel fuel at higher cost. This option can reduce emissions from the heavy-duty vehicle fleet and reduce greenhouse gas emissions.
7. Fischer Tropsch synthesis is one potentially promising future technology for conversion of stranded natural gas resources, or perhaps syngas to liquid transportation fuels, depending on the availability and cost of alternative supplies.

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